Hydrodynamic Controls on Acoustical and Optical Water Properties in Tropical Reefs

Geno Pawlak
Mechanical and Aerospace Engineering
University of California, San Diego
9500 Gilman Dr.
La Jolla, CA 92093-0411
phone: (858) 534-2343 email: pawlak@ucsd.edu

Mark Moline
School of Marine Science and Policy
University of Delaware
700 Pilottown Rd.
Lewis, DE 19958
phone: (302) 645-4263 email: mmoline@udel.edu

Award Number: N00014-12-1-0221

LONG-TERM GOALS

The general objective of the work underway is to develop a baseline characterization of the spatial and temporal variability in optical/acoustical water properties for tropical island environments in response to variations in physical forcing.

OBJECTIVES

Specifically, the project aims to address the following questions:

- What are the dominant space and time scales for variability in optical and acoustical water properties for tropical island reef environments?
- How do these vary for different reef zones, including forereef, reef flat, lagoon and channel areas?
- What are the dominant hydrodynamic controls across different reef environments?

  Tropical coral health can be significantly affected by sedimentation that can limit light availability, impact recruitment and bury coral colonies. The ongoing work will improve understanding of the dynamical processes that affect variability in optical and hydrodynamic properties for these important environments.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2012	**N/A**	**-**

4. TITLE AND SUBTITLE
Hydrodynamic Controls on Acoustical and Optical Water Properties in Tropical Reefs

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Mechanical and Aerospace Engineering University of California, San Diego 9500 Gilman Dr. La Jolla, CA 92093-0411

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**9**	

APPROACH

A two-week long set of focused field experiments was completed in March 2012 targeting temporal resolution of optical and acoustical water properties and flow hydrodynamics over a variety of reef environments with concurrent AUV-based spatial mapping. The field study site was located in the Republic of Palau (figure 1a), an island system including complex barrier reefs and multiple lagoon system. Palau has been the site of ongoing ONR-funded collaborative field work by the PIs, carried out in collaboration with UCSD SIO (PI: Terrill) and the Coral Reef Research Foundation in Koror (PI: Colin).

The observations included fixed instrumentation deployments and multiple AUV and vessel based measurements along the eastern side of the island system on a southeast facing narrow forereef in the vicinity of Ngadarak Reef (figure 1b). Bottom mounted instrumentation featured a 3m vertical spar with 3 ADVs along with a nearby (~3m) vertical array of optical sensors at the 10m isobath to enable definition of the source of particles influencing the optical and acoustical backscatter and to quantify the impact particles have on remote sensing capabilities. Optical instrumentation included a Wetlabs BB2F OBS sensor, a Wetlabs 3 channel/3 angle ECO Volume Scattering Function (VSF), and a Wetlabs AC-9 sensor. ADCPs with co-located thermistor chains were located at the 8m (1200kHz) and 17.5m (300kHz) isobaths to resolve cross-shore gradients. A bottom lander, including a 1200kHz ADCP, 6MHz ADV and a 2 channel OBS sensor, was deployed at multiple locations for short (1-2 day) periods.

AUV surveys were conducted daily to resolve spatial patterns in ABS/OBS and in flow structure, at varying times in the diurnal cycle. Several multi-vehicle surveys were carried out to improve spatio-temporal coverage. In addition vessel based CTD/PAR profiling was conducted during AUV missions. UCSD SIO also carried out vessel-based ADCP surveys of the nearby (southeast) channel during the ebb tide.

Further field observations are planned for early 2013 at a site yet to be determined, as part of collaborative work with Mark Merrifield (U Hawaii). The project has provided partial support for a research technician, Chris Colgrove, who has participated in field operations and experiment design.

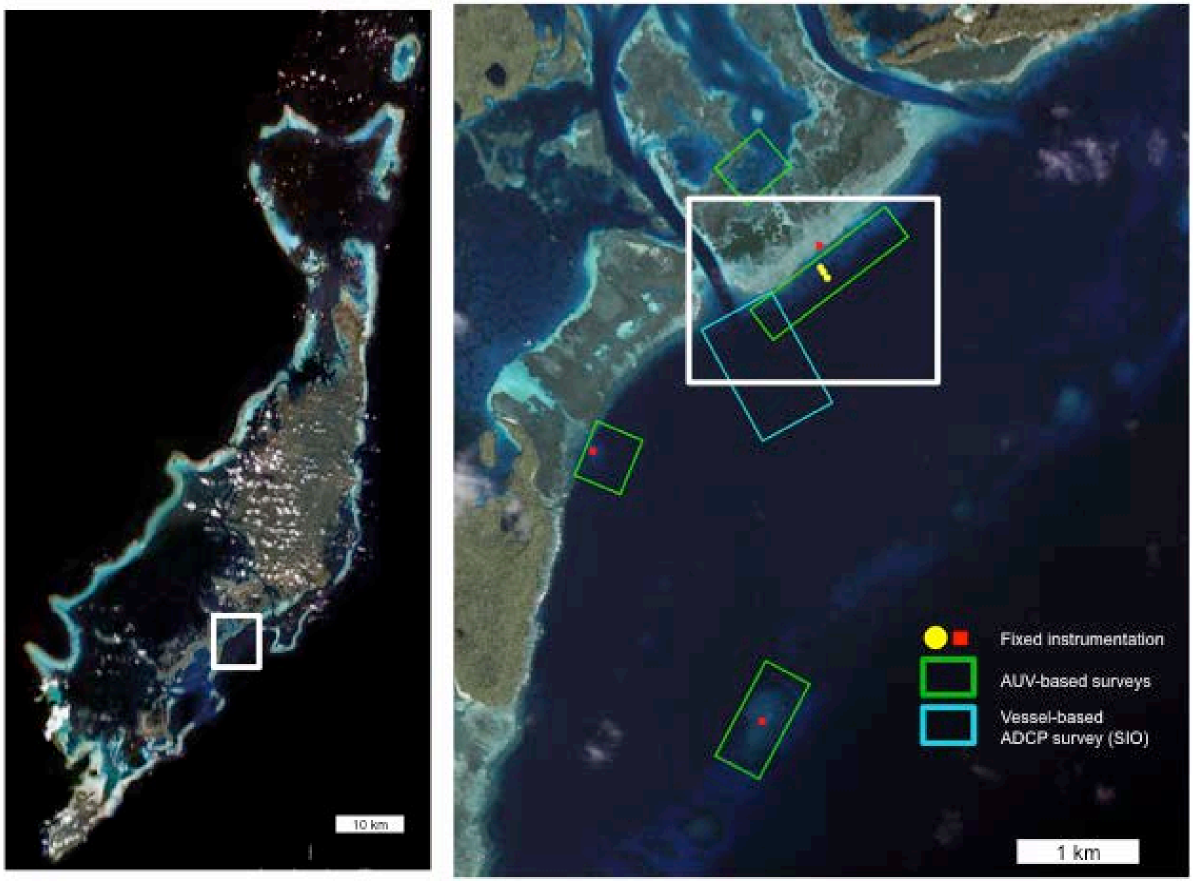

Figure 1 - a) Republic of Palau with study area highlighted in white. b) Study area with instrumentation sites and AUV, vessel-based survey areas highlighted.

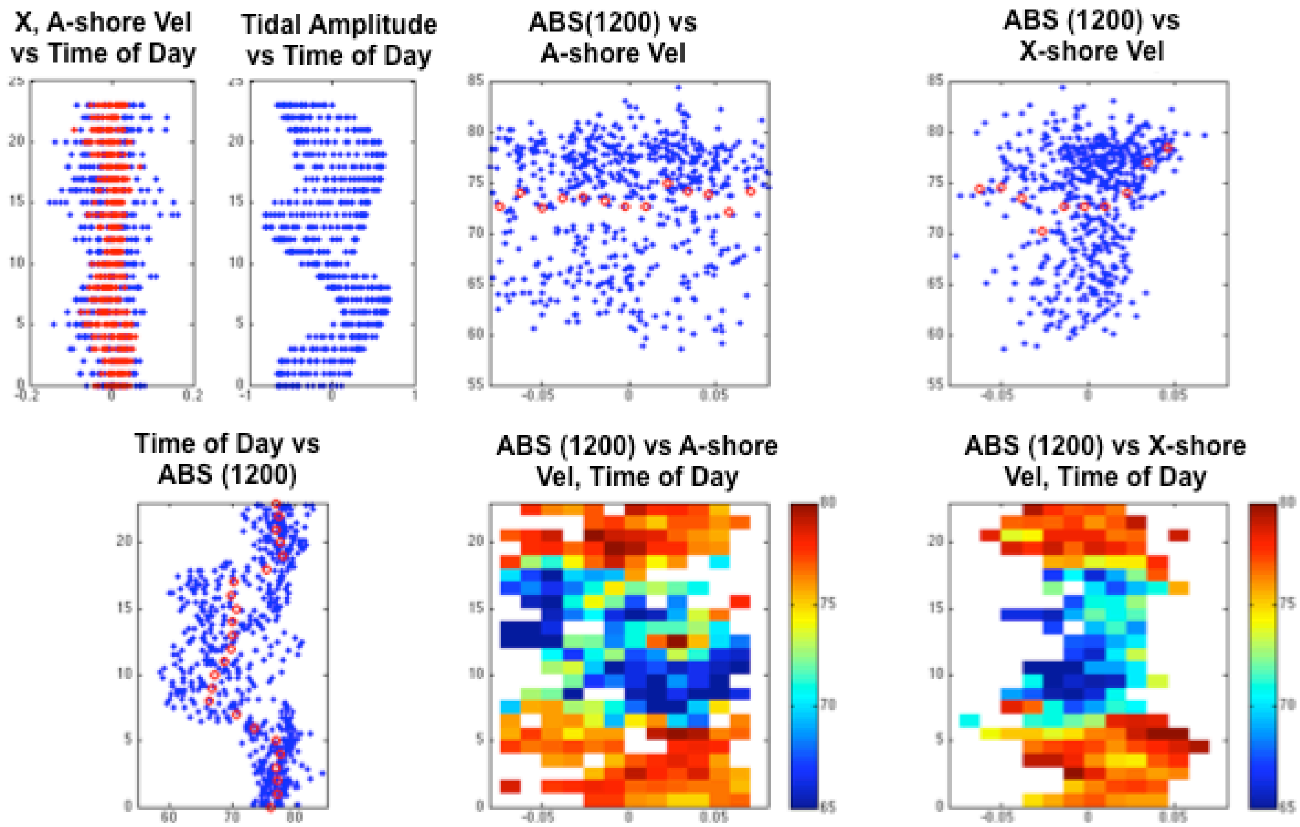

Figure 2 – Analysis of ABS at 1200kHz. Top row: a) cross-, along-shore velocities vs time of day (vert axis) for observational window; b) tidal amplitude vs time of day (vert axis); c) ABS vs alongshore velocity; d) ABS vs cross-shore velocity. Bottom row: e) ABS vs time of day (vert axis); f), g) ABS (color) vs time of day (vert axis), along-, cross-shore velocity. Scale for ABS is arbitrary.

WORK COMPLETED

Following the completion of the field observations in spring 2012, preprocessing and initial synthesis has been completed for fixed and mobile data sets. Preliminary analysis has focused on identifying first order forcing mechanisms for ABS and OBS time series data during the observational window and on relating acoustical and optical data sets with hydrodynamic variables.

RESULTS

Conditions during the March 2012 experiment included strong southeasterly winds (onshore at the experiment site) during the initial portion with accompanying increased waves, followed by a period of weak winds and rapidly diminishing swell. Currents were predominantly alongshore, but with a significant cross-shore flow component, which was surface intensified during the outflowing tide. Strong high-frequency (~hr^{-1}) pulses were observed in the alongshore current during the ebb that are possibly indicative of instability in the channel outflow to the southwest.

Relative acoustic backscatter (ABS) profiles were derived from individual ADCP beam echo intensity correcting for range and absorption using the sonar equation (Deines, 1999). Observed ABS patterns are similar at the 1200kHz ADCP (8m) and the 300kHz ADCP (17.5m). Depth averaged 1200kHz ABS for the 8m site averaged by time of day and current direction (figure 2) reveals an apparent influence of the diel cycle, with low backscatter during midday hours with maxima at dawn and dusk. The diel cycle is difficult to separate conclusively from tidal influences due to the relatively short data window as evident in the tidal amplitude versus time of day (figure 2a). Variation in 1200kHz ABS by tidal phase are not as clear as those by time of day, however, which suggests that the latter is dominant. Variations in 1200kHz ABS vs current (figure 2c,d, f, g) show a weak increase in backscatter with onshore flow.

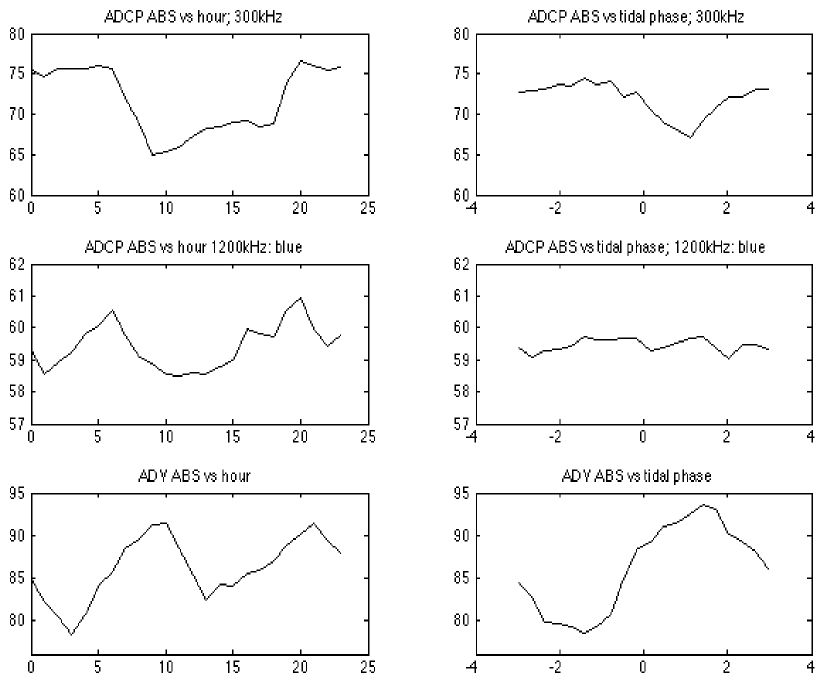

Figure 3 – Variation in ABS vs time of day (left column) and M2 tidal phase (right column) for 300kHz (top), 1200kHz (middle), and 6MHz (bottom).

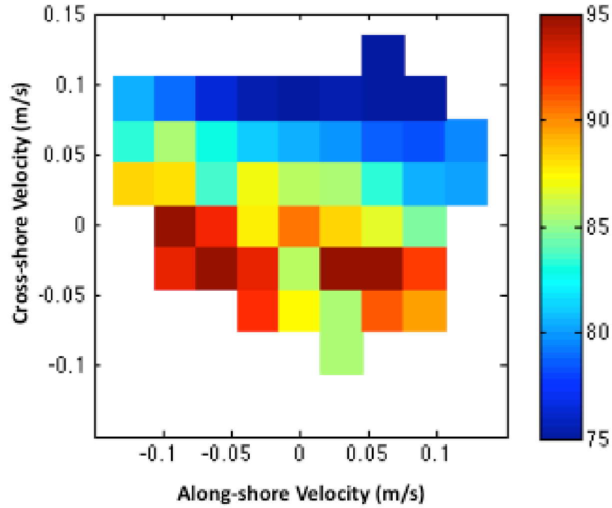

Figure - 4: 6Mhz ABS (color) vs along, cross-shore velocity. ABS units are arbitrary.

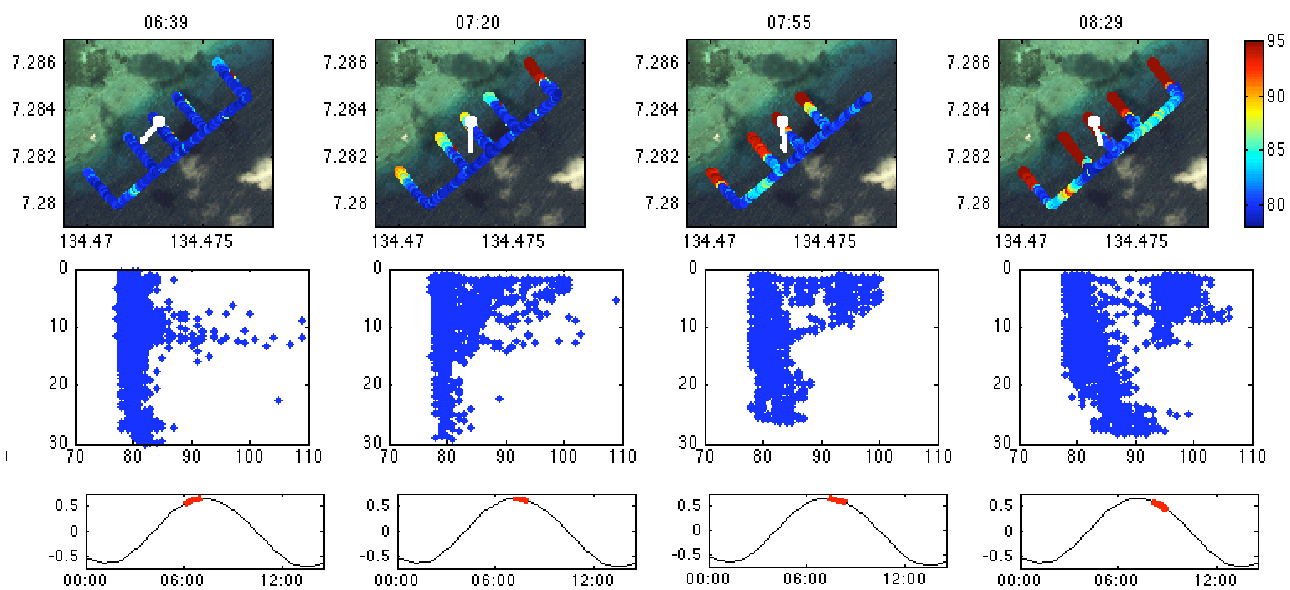

Figure 5 – Top row: AUV track over aerial image of Ngadarak forereef (Palau) for successive survey passes. Color indicates optical backscatter at 470nm (arb units). Bathymetry increases from 0-1 m on upper left to >100m on lower right. White circle indicates fixed instrument package location. White arrow indicates average current vector during each survey leg. Middle row: AUV-based optical backscatter (arb. units) vs depth corresponding to upper panels. Bottom row: Tidal variation with corresponding period highlighted in red.

ABS was also obtained at 2 and 3m above the bed at 6Mhz from the ADVs, located at the 10m isobath a short distance (~30m) from the 8m 1200kHz ADCP. The higher frequency backscatter from the 3m ADV (figure 3) shows a clearer tidal signal, in contrast with that from the two ADCPs. 6MHz ABS shows a strong directional dependence with higher values, on average, for offshore flow (figure 4). Optical backscatter (OBS) in the red, green and blue bands (not shown) all follow the high frequency ABS closely with the same directional dependence seen in figure 4. The relationship between OBS data further indicates that, during these periods, not only do the bulk particle signals change, but that the particle size also varies. Ratios of OBS for the different colors vary significantly with wave forcing (not shown)

Ongoing analysis is examining the relationship between optical and acoustical backscatter data at a range of frequencies. Analysis of scattering, absorption, and backscattering, shows more complex variations, with a strong diel signal, but with a tidal influence reflecting asymmetry in the flow patterns. Variogram analysis is also underway to identify temporal and spatial scales from time series and AUV data, respectively. More extensive investigation of relations between backscatter variability and hydrodynamic variables, including bed stress and turbulent dissipation will be completed in the second project year.

The direct effect of the variability in the hydrodynamically controlled inherent optical properties on remote sensing is also being investigated, including LIDAR penetration depth and traditional ocean color remote sensing techniques to discriminate bottom types. Preliminary calculations of remote sensing reflectance (R_{rs}) using the radiative transfer model HydroLight with the optical measurements as input variables indicates variations of 30% over the observational period (figure 6). These estimates, based on measurements at mid-depth, are likely conservative given that the highest ABS values were observed at the surface. The observations suggest that hydrodynamic forcing can result in significant, measurable variations in remotely sensed variables. This approach may link remote sensing to the physical dynamics for use as a tool in these reef systems.

The spectral signature of the optical variations was consistent with that observed for whiting events as described by Dierssen et al 2009. The spectra can be attributed to micron-sized aragonite particles. The backscatter variation across the spectra related earlier to wave forcing has been previously observed for whiting events (Dierssen et al. 2009, McKee and Cunningham, 2005) and has been suggested as resulting from a dominance of a single particle type.

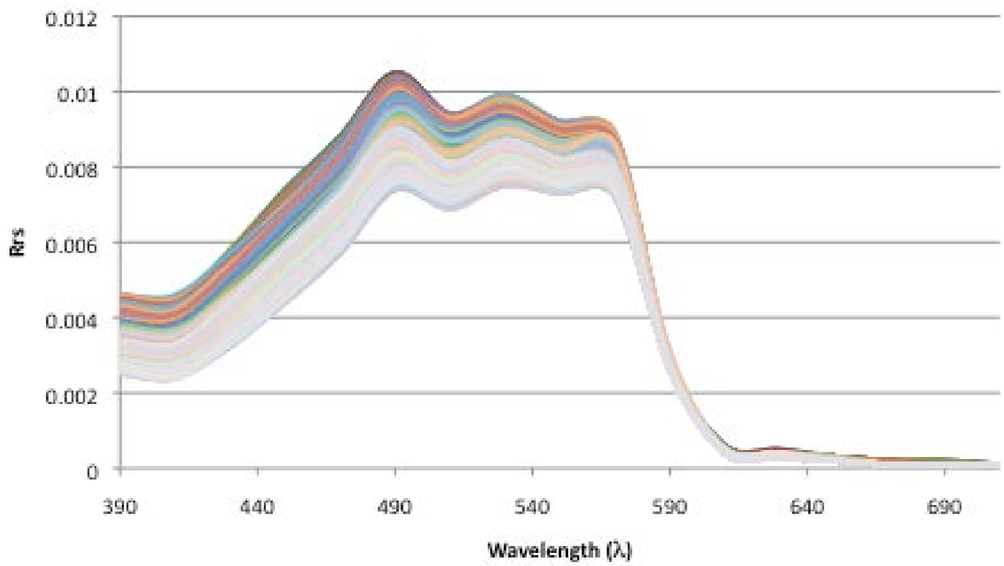

Figure 6 – Remote sensing reflectance spectra for observational period, as derived using HydroLight from measured optical data.

IMPACT/APPLICATIONS

Coral reefs are ecologically rich zones supporting vast ecosystems. They are a dominant feature of coastal environments between the latitudes of 25S and 25N (Hoegh-Guldberg 1999). Tropical coral health can be significantly affected by sedimentation that can limit light availability, impact recruitment and bury coral colonies (Ogston et al. 2004, Fabricius 2005). The extent to which sedimentation affects benthic communities is dependent on temporal and spatial extent of events combined with local hydrodynamic characteristics. The work underway will improve understanding of the dynamical processes that affect variability in optical and hydrodynamic properties for these important environments.

The variations in measured and derived optical and acoustical properties described above suggest that hydrodynamic forcing can introduce significant, measurable changes in remotely sensed variables. Accurate assessment and prediction of optical and acoustic properties is critical for remote sensing applications. The work described above is establishing a general baseline of the variability in these critical water properties and to resolve the interactions with physical and biological forcing for tropical environments. The observations and analysis presently underway will also enable more general characterization of bed morphologies in reef zones and will lay a foundation for remote sensing of bed characteristics from aerial and satellite imagery. Furthermore, the observations suggest that remote sensing can also be useful in assessing hydrodynamic characteristics for inaccessible reef areas.

RELATED PROJECTS

The project is being carried out concurrently and in close collaboration with other ONR funded work in Palau (Moline, Terrill), leveraging much of the equipment required for this study. The work proposed here is also providing a critical foundation for a proposed ONR Departmental Research

Initiative (DRI) focusing on tropical island circulation (TROPIC, ONR, 2012) and would enable necessary continuity between ongoing ONR efforts and the TROPIC program.

The work described here has also been carried out in parallel to a separate, complementary ONR funded project that is targeting parameterization of wave and current drag for flow over complex roughness. Some of the AUV surveys and hydrodynamics observations described above provide data relevant to both projects and some analysis efforts overlap. Further observations in support of this project will also yield useful data sets for the reef roughness work.

The work described above is also being coordinated with an NSF funded project (PI: Merrifield) targeting wave transformation and coastal flooding for island shorelines. Project PIs are collaborating to carry out further observations that will enable extension of the work described here and providing an additional data set for analysis.

REFERENCES

Deines K. L., 1999, Backscatter estimation using Broadband acoustic Doppler current profilers. Proceedings of the IEEE Sixth Working Conference on Current Measurement. San Diego, California.

Dierssen, H. M., R. C. Zimmerman, and D. J. Burdige. 2009. Optics and remote sensing of Bahamian carbonate sediment whitings and potential relationship to wind-driven Langmuir circulation. Biogeosciences, 6, 487–500, 2009

Fabricius, K.E., 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. Mar. Poll. Bull. 50, 125–146.

Hoegh-Guldberg, O., 1999: Climate change, coral bleaching and the future of the world's coral reefs. Mar. Freshw. Res., 50, 839-866.

McKee and Cunningham, 2005. Evidence for wavelength dependence of the scattering phase function and its implication for modeling radiance transfer in shelf seas. Appl. Opt. 44, 126-135.

Ogston, A.S., Storlazzi, C.D., Field, M.E., Presto, M.K., 2004. Sediment resuspension and transport patters on a fringing reef flat, Molokai, Hawaii. Coral Reefs 23, 559-569.